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(54) **COMPOSITIONS PERFLUOROELASTOMERES**

(54) **PERFLUOROELASTOMER COMPOSITIONS**

(57) La présente invention concerne un composé perfluoroélastomère qui présente une meilleure aptitude au traitement et qui renferme une perfluorooléfine, un perfluorovinyle éther et un site de polymérisation renfermant un halogène dans lequel le polymère ne contient pratiquement pas de fractions ionisables. L'invention concerne également des procédés de fabrication de tels copolymères ainsi que des articles réalisés à partir de ces copolymères.

(57) A perfluoroelastomer compound having improved processability comprising a perfluoroolefin, a perfluorovinyl ether and a halogen-containing cure site, where the polymer contains substantially no ionizable moieties; and processes for making such copolymers; and articles made therefrom.



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(21) International Application Number: PCT/US99/03490 (22) International Filing Date: 18 February 1999 (18.02.99) (30) Priority Data: 60/079,061 23 March 1998 (23.03.98) US (71) Applicant: DYNEON LLC [US/US]; 6744 33rd Street North, Oakdale, MN 55128 (US). (72) Inventor: GROOTAERT, Werner, M.; P.O. Box 33427, Saint Paul, MN 55133-3427 (US). (74) Agent: LILLY, James, V.; Minnesota Mining and Manufacturing Company, Office of Intellectual Property Counsel, P.O. Box 33427, Saint Paul, MN 55133-3427 (US).		(81) Designated States: BR, CA, CN, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i>
(54) Title: PERFLUOROELASTOMER COMPOSITIONS (57) Abstract A perfluoroelastomer compound having improved processability comprising a perfluoroolefin, a perfluorovinyl ether and a halogen-containing cure site, where the polymer contains substantially no ionizable moieties; and processes for making such copolymers; and articles made therefrom.		

PERFLUOROELASTOMER COMPOSITIONS

5

FIELD OF THE INVENTION

This invention relates to peroxide-curable perfluoroelastomer compositions which have excellent processability, and which when cured, have excellent physical properties.

10

BACKGROUND OF THE INVENTION

Perfluoroelastomers (elastomeric perfluoropolymers) are polymeric materials which exhibit outstanding high temperature tolerance and chemical resistance.

Consequently, such compositions are particularly adapted for use as seals and gaskets in systems in which elevated temperatures and/or corrosive chemicals are encountered. They are useful in industries such as, chemical processing, semiconductor, aerospace, petroleum, etc.

The outstanding properties of perfluoropolymers are largely attributable to the stability and inertness of the copolymerized perfluorinated monomer units which make up the major portion of the polymer backbone, e.g., tetrafluoroethylene and perfluoro(alkyl vinyl) ethers. In order to completely develop elastomeric properties, perfluoropolymers are typically crosslinked, i.e. vulcanized. To this end, a small percentage of a cure site monomer is copolymerized with the perfluorinated monomer units. Cure site monomers containing at least one bromo or iodo group are known. Such cure site monomers, when combined with a peroxide and a coagent, will provide a suitably cured composition.

Perfluoroelastomers are very expensive materials, and therefore are only used in situations where no other material will do the job. In view of the very high raw material costs, scrap rates during the molding operation must be kept to a minimum. Unfortunately, perfluoroelastomers are known to be very difficult to process with respect to compounding, flow characteristics and mold release. When conventional initiators are used to produce the polymers (e.g., persulfates) the polymeric end groups are typically of an ionic and/or acidic nature. These ionizable polymer end-groups, that are normally present, are prone to undesirable reactions with some commonly used additives, (e.g., acid

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~~Preferably the perfluoroelastomer is substantially free of ionizable end groups selected from the group consisting of carboxylate or carboxylic acid end-groups and sulfonate or sulfonic acid end groups~~ acceptors). Examples of commonly used acid acceptors are zinc oxide, calcium hydroxide, calcium carbonate, magnesium oxide, etc. They are used in the compound formulation to bind any HF or other acids that might be generated at the high temperatures where perfluoroelastomers must function. [Page 2a]

Perfluoroelastomer compounds that show very good processing characteristics are much desired. Because many applications for these polymers also require good sealing capabilities, the steps to improve processability are preferably not detrimental to critical physical properties such as compression set resistance.

10

SUMMARY OF THE INVENTION

The perfluoroelastomers compounds of this invention employ a perfluoroelastomer that is prepared using an initiator combination of an oxidizer and a perfluoroalkyl sulfinate of type R_fSO_2Na . The copolymers prepared in this manner surprisingly can be processed like other elastomer gums. They are easy to process on conventional 2 roll mills, or mixing devices, i.e. the mills or mixing devices need not be heated above room temperature. Their compound viscosity does not increase when acid acceptors, such as $Ca(OH)_2$, are added. The perfluoroelastomers also show improved physical properties (e.g. compression set resistance).

20

One embodiment of the invention provides a peroxide curable perfluoroelastomer compound that is easily processable and is essentially free of ionizable end groups. ^(->) By "essentially free" of such groups it is meant that less than 10% of these end groups are ionizable groups. The compound of this embodiment comprises:

25

- A) a perfluoroelastomer containing interpolymerized units derived from 1) a perfluoroolefin, 2) a perfluorovinyl ether selected from the group consisting of perfluoro(alkyl vinyl) ethers, perfluoro(alkoxy vinyl) ethers, and mixtures thereof, and 3) a cure site component containing a halogen group capable of participation in a peroxide cure reaction, selected from the group consisting of fluorinated olefins having at least one such halogen group, fluorinated vinyl ethers having at least one such halogen group, chain transfer agents containing at least one such halogen group, and initiators containing at least one such halogen group, and mixtures thereof, with the

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2a

WO-A-97/02300 describes a process for the preparation of a fluorine-containing polymer, comprising polymerizing, in an aqueous emulsion or suspension, a fluorine-containing olefin, wherein the initiator is a combination of a fluoroaliphatic sulfinate or sulfinic acid and an oxidizing agent selected from the group consisting of chorate ion, bromate ion and hypochorite ion, and provided that said fluoroaliphatic sulfinate or fluoroaliphatic sulfinic acid and said oxidizing agent are water-soluble.

FR-A-2 305 462 discloses fluoropolymers made by copolymerizing a small amount of bromotrifluoroethylene or bromotetrafluorobutene with certain combinations of monomers comprising selected fluorine-containing compounds. A fluoropolymer composition useful in the manufacture of cured fluoropolymer articles can be made by mixing the resulting fluoropolymer or a closely related fluoropolymer with an organic peroxide such as dialkyl peroxide, and preferably also adding a divalent metal oxide and/or hydroxide and a suitable co-agent such as triallyl isocyanurate.

US-A-5,285,002 describes a method for the preparation of a fluorine-containing polymer comprising polymerizing, under free radical conditions, an aqueous emulsion or suspension of a polymerizable mixture comprising a fluoroaliphatic radical containing sulfinate, and an oxidizing agent capable of oxidizing said sulfinate to a sulfonyl radical.

proviso that the cure site component contains substantially no nitrile groups, and

B) a peroxide curative.

In another embodiment, the invention provides a peroxide curable
5 perfluoroelastomer compound that is easily processable comprising:

A) a perfluoroelastomer substantially free of ionizable end groups, wherein the
perfluoroelastomer contains interpolymerized units derived from 1) a
perfluoroolefin, 2) a perfluorovinyl ether selected from the group consisting
of perfluoro(alkyl vinyl) ethers, perfluoro(alkoxy vinyl) ethers, and
10 mixtures thereof, and 3) a cure site component containing a bromine or
iodine atom capable of participation in a peroxide cure reaction, selected
from the group consisting of brominated or iodinated olefins having at least
one such atom, brominated or iodinated vinyl ethers having at least one
such atom, brominated or iodinated chain transfer agents, brominated or
15 iodinated initiators, and mixtures thereof; and

B) a peroxide curative.

The present invention also provides a method for improving the processability of
perfluoroelastomers, comprising: polymerizing, under free-radical conditions, an aqueous
emulsion or suspension of a polymerizable mixture comprising a perfluoroolefin and a
20 perfluoroalkyl vinyl ether or a perfluoroalkoxy vinyl ether and mixtures thereof, a
halogen-containing cure-site component capable of participation in a peroxide cure
reaction, a fluoroaliphatic-radical containing sulfinate, and an oxidizing agent capable of
oxidizing said sulfinate to a sulfonyl radical, with the proviso that the cure site component
contains substantially no nitrile groups.

25 The present invention also provides a method for improving the processability of
perfluoroelastomers, comprising: polymerizing, under free-radical conditions, an aqueous
emulsion or suspension of a polymerizable mixture comprising a perfluoroolefin and a
perfluoroalkyl vinyl ether or a perfluoroalkoxy vinyl ether and mixtures thereof, a
bromine- or iodine-containing cure-site component, a fluoroaliphatic-radical containing
30 sulfinate, and an oxidizing agent capable of oxidizing said sulfinate to a sulfonyl radical.

The invention further relates to cured and uncured articles made from such curable
compounds.

DETAILED DESCRIPTION

The compositions of the present invention comprise peroxide curable
 5 perfluoroelastomers which are characterized by improved processability and less reactivity
 to bases. These compositions comprise a) a perfluoroelastomer having copolymerized
 units of a perfluoroolefin, a perfluorovinyl ether and a cure site component having at least
 one bromine- or iodine-containing moiety, and b) a compound which acts as a curative for
 the perfluoroelastomer. The perfluoroelastomers are substantially free of ionizable end
 10 groups, such as those reactive with bases. This does not preclude the presence of cure
 sites in the perfluoroelastomers needed for crosslinking.

Examples of suitable perfluorinated olefins useful in the invention include
 tetrafluoroethylene and hexafluoropropylene.

Examples of suitable perfluorinated vinyl ethers are those of the formula
 15
$$\text{CF}_2=\text{CFO}(\text{R}_f\text{O})_n (\text{R}'_f\text{O})_m \text{R}_f \quad (\text{I})$$

where R_f and R'_f are different linear or branched perfluoroalkylene groups of 2-6 carbon
 atoms, m and n are independently 0-10, and R_f is a perfluoroalkyl group of 1-6 carbon
 atoms.

A preferred class of perfluoro(alkyl vinyl) ethers includes compositions of the
 20 formula
$$\text{CF}_2=\text{CFO}(\text{CF}_2\text{CFXO})_n \text{R}_f \quad (\text{II})$$

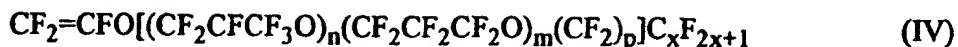
where X is F or CF_3 , n is 0-5, and R_f is a perfluoroalkyl group of 1-6 carbon atoms.

Most preferred perfluoro(alkyl vinyl) ethers are those wherein n is 0 or 1 and R_f
 contains 1-3 carbon atoms. Examples of such perfluorinated ethers include
 perfluoro(methyl vinyl) ether, perfluoro(ethyl vinyl) ether, and perfluoro(propyl vinyl)
 25 ether. Other useful monomers include compounds of the formula



where R_f is a perfluoroalkyl group having 1-6 carbon atoms, $m=0$ or 1, $n=0-5$, and $Z=\text{F}$ or
 CF_3 .

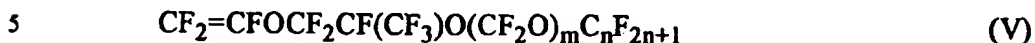
Preferred members of this class are those in which R_f is C_3F_7 , $m=0$, and $n=1$.
 30 Additional perfluoro(alkyl vinyl) ether monomers useful in the invention include
 compounds of the formula



where m and n=1-10, p=0-3, and x=1-5.

Preferred members of this class include compounds where n=0-1, m=0-1, and x=1.

Examples of perfluoro(alkoxy vinyl) ethers useful in the invention include



where n=1-5, m=1-3, and where, preferably, n=1.

Specific examples of useful perfluorovinyl ethers useful in the invention include

$\text{CF}_2=\text{CFOCF}_2\text{OCF}_2\text{CF}_2\text{CF}_3$, $\text{CF}_2=\text{CFOCF}_2\text{CF}_3$, $\text{CF}_2=\text{CFO}(\text{CF}_2)_3\text{OCF}_3$, and $\text{CF}_2=\text{CFOCF}_2\text{CF}_2\text{OCF}_3$.

Mixtures of perfluoro(alkyl vinyl) ethers and perfluoro(alkoxy vinyl) ethers may also be used.

Preferred copolymers are composed of tetrafluoroethylene and at least one perfluoro(alkyl vinyl) ether as principal monomer units. In such copolymers, the copolymerized perfluorinated ether units constitute from about 15-50 mole percent of total monomer units in the polymer.

The cure site component used in the present invention is a halogen containing material that is capable of participation in a peroxide cure reaction. Typically the halogen is bromine or iodine. Suitable cure-site components include terminally unsaturated monoolefins of 2 to 4 carbon atoms such as bromodifluoroethylene, bromotrifluoroethylene, iodotrifluoroethylene, and 4-bromo-3,3,4,4-tetrafluorobutene-1. Examples of other suitable cure site components include $\text{CF}_2=\text{CFOCF}_2\text{CF}_2\text{Br}$, $\text{CF}_2=\text{CFOCF}_2\text{CF}_2\text{CF}_2\text{Br}$, and $\text{CF}_2=\text{CFOCF}_2\text{CF}_2\text{CF}_2\text{OCF}_2\text{CF}_2\text{Br}$. Preferably, all or essentially all of these components are ethylenically unsaturated monomers.

Other useful cure-site components are brominated or iodinated chain transfer agents and initiators. Examples of useful chain transfer agents include perfluoroalkyl bromides or iodides. Examples of useful initiators include $\text{NaO}_2\text{SC}_2\text{F}_4\text{OF}_4\text{X}$ (where X is Br or I).

Suitable peroxide curatives for use in the invention are those which generate free radicals at curing temperatures. A dialkyl peroxide or a bis(dialkyl peroxide) which decomposes at a temperature above 50° C is especially preferred. In many cases it is preferred to use a di-tertiarybutyl peroxide having a tertiary carbon atom attached to

peroxy oxygen. Among the most useful peroxides of this type are 2,5-dimethyl-2,5-di(tertiarybutylperoxy)hexyne-3 and 2,5-dimethyl-2,5-di(tertiarybutylperoxy)hexane. Other peroxides can be selected from such compounds as dicumyl peroxide, dibenzoyl peroxide, tertiarybutyl

- 5 perbenzoate, α,α' -bis(t-butylperoxy-diisopropylbenzene), and di[1,3-dimethyl-3-(t-butylperoxy)-butyl]carbonate. Generally, about 1-3 parts of peroxide per 100 parts of perfluoroelastomer is used.

Another material which is usually blended with the composition as a part of the curative system is a coagent composed of a polyunsaturated compound which is capable of
10 cooperating with the peroxide to provide a useful cure. These coagents can be added in an amount equal to 0.1 and 10 parts per hundred parts perfluoroelastomer, preferably between 2-5 parts per hundred parts perfluoroelastomer. Examples of useful coagents include triallyl cyanurate; triallyl isocyanurate; tri(methylallyl isocyanurate; tris(diallylamine)-s-triazine; triallyl phosphite; N,N-diallyl acrylamide; hexaallyl phosphoramidate; N,N,N',N'-
15 tetraalkyl tetraphthalamide; N,N,N',N'- tetraallyl malonamide; trivinyl isocyanurate; 2,4,6-trivinyl methyltrisiloxane; and tri(5-norbornene-2-methylene)cyanurate. Particularly useful is triallyl isocyanurate.

Other useful coagents include the bis-olefins disclosed in EPA 0 661 304 A1, EPA 0 784 064 A1 and EPA 0 769 521 A1.

- 20 Additives, such as carbon black, stabilizers, plasticizers, lubricants, fillers, and processing aids typically utilized in perfluoroelastomer compounding can be incorporated into the compositions of the present invention, provided they have adequate stability for the intended service conditions. In particular, low temperature performance can be enhanced by incorporation of perfluoropolyethers (cf. U.S. Pat No. 5,268,405).

- 25 Carbon black fillers are used in elastomers as a means to balance modulus, tensile strength, elongation, hardness, abrasion resistance, conductivity, and processability of the compositions. Suitable examples include MT blacks (medium thermal black) designated N-991, N-990, N-908, and N-907, and large particle size furnace blacks. When used, 1-70 phr of large size particle black is generally sufficient.

- 30 In addition, fluoropolymer fillers may also be present in the composition. Generally, from 1 to 50 parts per hundred perfluoroelastomer of a fluoropolymer filler is used. The fluoropolymer filler can be finely divided, easily dispersed plastic

fluoropolymer that is solid at the highest temperature utilized in fabrication and curing of the perfluoroelastomer composition. By solid, it is meant that the fluoroplastic, if partially crystalline, will have a crystalline melting temperature above the processing temperature(s) of the perfluoroelastomer(s). Such finely divided, easily dispersed
 5 fluoroplastics are commonly called micropowders or fluoroaditives. Micropowders are ordinarily partially crystalline polymers.

The method of this invention comprises the use of perfluorosulfinate and an oxidizing agent in a free-radical polymerization process. The polymerization process includes free-radical polymerization of monomers alone or as solutions, emulsions, or
 10 dispersions in an organic solvent or water. Polymerization in an aqueous emulsion or suspension is often preferred because of the rapid and nearly complete conversion of monomers, easy removal of the heat of polymerization, and ready isolation of the polymer. Emulsion or suspension polymerization typically involves polymerizing monomers in an aqueous medium in the presence of an inorganic free-radical initiator system and
 15 surfactant or suspending agent.

Aqueous emulsion polymerization can be carried out continuously under steady-state conditions in which, for example, monomers, water, surfactants, buffers and catalysts are fed continuously to a stirred reactor under optimum pressure and temperature conditions while the resulting emulsion or suspension is removed continuously. An
 20 alternative technique is batch or semibatch polymerization by feeding the ingredients into a stirred reactor and allowing them to react at a set temperature for a specified length of time or by charging ingredients into the reactor and feeding the monomer into the reactor to maintain a constant pressure until a desired amount of polymer is formed.

A class of the fluoroaliphatic sulfinates useful in this invention are found in U.S.
 25 patent No. 5,285,002 incorporated herein by reference and can be represented by the following general formulae



or



30 wherein R^3_f represents a monovalent fluoroaliphatic radical having, for example, from 1 to 20 carbon atoms, preferably 4 to 10 carbon atoms, R^2_f represents a polyvalent, preferably

divalent, fluoroaliphatic radical having, for example, from 1 to 20 carbon atoms, preferably from 2 to 10 carbon atoms, M represents a hydrogen atom or cation with valence x, which is 1 to 2, and is preferably 1, and n is 1 to 4, preferably 1 or 2.

The monovalent fluoroaliphatic radical, R^3_f is a fluorinated, stable, inert, non-polar, saturated moiety. It can be straight chain, branched chain, and, if sufficiently large, cyclic, or combinations thereof, such as alkyl cycloaliphatic radicals. Generally, R^3_f will have 1 to 20 carbon atoms, preferably 4 to 10, and will contain 40 to 83 weight percent, preferably 50 to 78 weight percent fluorine. The preferred compounds are those in which the R^3_f group is fully or substantially completely fluorinated, as in the case where R^3_f is perfluoroalkyl, C_nF_{2n+1} , where n is 1 to 20.

The polyvalent, preferably divalent, fluoroaliphatic radical, R^2_f is a fluorinated, stable, inert, non-polar, saturated moiety. It can be straight chain, branched chain, and, if sufficiently large, cyclic or combinations thereof, such as alkylcycloaliphatic diradicals. Generally, R^2_f will have 1 to 20 carbon atoms, preferably 2 to 10. The preferred compounds are those in which the R^2_f group is perfluoroalkylene, C_nF_{2n} , where n is 1 to 20, or perfluorocycloalkyl, C_nF_{2n} , where n is 5 to 20.

With respect to either R^3_f or R^2_f the skeletal chain of carbon atoms can be interrupted by divalent oxygen, hexavalent sulfur or trivalent nitrogen hetero atoms, each of which is bonded only to carbon atoms, but preferably where such hetero atoms are present, such skeletal chain does not contain more than one said hetero atom for every two carbon atoms. An occasional carbon-bonded hydrogen atom, iodine, bromine, or chlorine atom may be present; where present, however, they preferably are present not more than one for every two carbon atoms in the chain. Where R^3_f or R^2_f is or contains a cyclic structure, such structure preferably has 6 ring member atoms, 1 or 2 of which can be said hetero atoms, e.g., oxygen and/or nitrogen. Examples of R^3_f radicals are fluorinated alkyl, e.g., C_4F_9-- , C_6F_{13--} , C_8F_{17--} , alkoxyalkyl, e.g., $C_3F_7OCF_2--$. Examples of R^2_f are fluorinated alkylene, e.g., $--C_4F_8--$, $--C_8F_{16--}$. Where R^3_f is designated as a specific radical, e.g., C_8F_{17--} , it should be understood that this radical can represent an average

structure of a mixture, e.g., C_6F_{13} -- to $C_{10}F_{21}$ --, which mixture can also include branched structures.

Representative fluoroaliphatic sulfinate compounds useful in the method of this invention include the following:

- 5 CF_3SO_2Na
- $C_4F_9SO_2H$
- $C_8F_{17}SO_2Na$
- $CF_3C(Cl)_2CF_2SO_2K$
- $Cl(CF_2)_8OC_2F_4SO_2Na$
- 10 $Cl(CF_2)_xCF_2SO_2Na$, where x is 0,1,3,4,7,9
- $NaO_2SC_8F_{16}SO_2Na$
- $NaO_2SC_6F_{12}SO_2Na$
- $NaO_2SC_2F_4OC_2F_4SO_2Na$
- $NaO_2SC_2F_4OC_2F_4X$, where X is Br or I
- 15 $NaO_2S[C_4F_8O]_nC_3F_6SO_2Na$
- $NaO_2SCF_2O(CF_2CF_2O)_m(CF_2O)_nCF_2SO_2Na$
- $(CF_3)_2NCF_2CF_2SO_2Na$
- $(C_2F_5)_2NCF_2CF_2SO_2Na$
- $N(C_2F_4SO_2Na)_3$
- 20 $NaO_2SC_8F_{16}SO_2F$
- $NaO_2SCF_2CF_2-N \begin{array}{c} \diagup \quad \diagdown \\ F \end{array} N-CF_2CF_2SO_2Na$
- $O \begin{array}{c} \diagup \quad \diagdown \\ F \end{array} N - CF_2CF_2SO_2Na$
- $NaO_2SC_3F_6O(C_4F_8O)_nC_3F_6SO_2Na$ where n is 4 to 8.

- Combinations of monosulfates, disulfates, and trisulfates can be used,
- 25 depending on whether it is desired to use sulfinate as an initiator, a monomer, or both. When polyvalent sulfates, such as those represented by Formula VII, are used, the sulfinate is a monomer and the fluorinated moiety is incorporated into the polymer backbone. When monosulfates are used the fluorinated moiety is incorporated as a polymer end group.

The amount of fluoroaliphatic sulfinates used in the method(s) of the invention can vary, depending, for example, on the molecular weight of polymer desired. Preferably the amount of fluoroaliphatic sulfinate is from 0.01 to 50 mole %, and most preferably from 0.05 to 10 mole %, of sulfinate compound based on total quantity of monomers.

5 In addition to the sulfinate, other reducing agents can be present, such as sodium, potassium or ammonium sulfites, bisulfite, metabisulfite, hyposulfite, thiosulfite, phosphite, sodium or potassium formaldehyde sulfoxylate or hypophosphite. Activators such as ferrous, cuprous, and silver salts, may also be present.

10 The oxidizing agent used in the method of the invention is water soluble and is capable of converting the sulfinate to a sulfonyl moiety. The sulfonyl radical produced in the method of the invention is believed to eliminate SO_2 and form a fluorinated radical that initiates the polymerization of the ethylenically unsaturated monomers.

A number of useful oxidizing agents are known as taught in U.S. Patent 5,285,002. Representative examples of such useful oxidizing agents are sodium, potassium, and
15 ammonium persulfates, perphosphates, perborates, percarbonates, bromates, chlorates and hypochlorites. Other useful oxidizing agents include cerium IV compounds such as $(\text{NH}_4)_2\text{Ce}(\text{NO}_3)_6$. It is understood that this list of oxidizing agents is exemplary only. One of ordinary skill in the art will recognize that there are other oxidizing agents useful in the invention based upon this disclosure.

20 The amount of oxidizing agent used can vary depending on the particular oxidizing agent and sulfinate employed. Typically an equimolar amount or less (based on the amount of sulfinate) is used.

The curable compositions of the present invention may be prepared by mixing a perfluoroelastomer, a peroxide curative, and other additives in conventional rubber
25 processing equipment. Such equipment includes rubber mills, internal mixers, such as Banbury mixers, and mixing extruders.

Prior to the present invention, it was difficult to prepare compositions containing perfluoroelastomer. Typically the compositions required the use of heated processing equipment to keep the compositions from forming crumbly masses. The
30 perfluoroelastomer compounds of this invention do not require the use of heated rolls or processing equipment during compounding. They can be prepared at ambient temperatures without forming a crumbly mass. The substantial lack of reactive end groups

on the perfluoroelastomers is at least partially responsible for this. The substantial lack of these groups minimizes reactive problems, such as exotherm or significant viscosity increase during addition of acid acceptors. The lack of compound viscosity increase prevents problems with flow and filling of mold cavities. The ability to compound at lower temperatures minimizes the problem of premature onset of the cure or crosslinking reaction.

The curable compositions of the present invention are useful in production of articles such as gaskets, tubing, and seals. Such articles are produced by molding a compounded formulation of the curable composition with various additives under pressure, curing the part, and then subjecting it to a post cure cycle. During the molding step, the perfluoroelastomers of the invention demonstrate an additional advantage. Lower viscosity is evidenced by faster mold filling or the lower pressures required. Improved mold release is apparent when removing the press cured part or injection molded part from the mold. The cured compositions have excellent thermal stability and chemical resistance. They are particularly useful in applications such as seals and gaskets for manufacturing semiconductor devices, and in seals for high temperature automotive uses.

The following examples will further demonstrate the present invention. In these examples, the properties were tested as follows.

Mooney viscosity was determined by ASTM D 1646-96 (ML 1+10@121°C).

Results are reported in Mooney units.

Cure Rheology Tests were run on compounded admixtures using a Monsanto Moving Die Rheometer (MDR) Model 2000 in accordance with ASTM D 5289-95 at 177°C, no preheat, 12 minute elapsed time (unless otherwise specified) and a 0.5° arc. Values were obtained for Minimum torque (ML), Maximum torque (MH), i.e., highest torque attained during specified period of time when no plateau or maximum was obtained, were measured. Also reported were: t_{s2} (time for torque to increase 2 units above ML), $t'50$ (time for torque to reach $ML + 0.5[MH-ML]$), and $t'90$ (time for torque to reach $ML + 0.9[MH-ML]$). Torque is reported as deci Newton meters (dNm).

Press-cured samples (150 x 150 x 2.0 mm sheets, unless otherwise noted) were prepared for physical property determination by pressing at about 6.9 MegaPascals (MPa) for the indicated amount of time and temperature.

Post-cured samples were prepared by placing a press-cured sample in a circulating air oven. The oven was maintained at the indicated temperatures and the samples treated for the indicated amount of time.

Force per unit area is reported as Mega Pascals (MPa).

- 5 Physical properties were obtained according to ASTM D-412 and Hardness was obtained according to ASTM D 2240.

Compression sets were determined by ASTM D 395-89 Method B with 0.139 inch (3.5 mm) O-rings compressed for 70 hours at 200°C. Results are reported as %.

10

EXAMPLE 1

- Several fluoropolymers were prepared in a manner similar to Example 1 of U.S. Patent No. 5,285,002 except the monomers and other ingredients used are as listed below in gram weight quantities. The monomers used were tetrafluoroethylene (TFE), perfluoromethyl vinyl ether (PMVE) and bromotrifluoroethylene (BTFE). (NH₄)₂S₂O₈
 15 was identified as APS. The fluorochemical sulfinate (C₄F₉SO₂Na) was prepared as discussed in U.S. Patent No. 5,285,002.

	Comparative Polymer A	Polymer A
Deionized (DI) water:	2,777	2,774
20 C ₇ F ₁₅ COONH ₄ :	15.9	15.9
K ₂ HPO ₄ :	10	10
C ₄ F ₉ SO ₂ Na:	-----	4
Precharge monomers:		
TFE:	142	140
25 PMVE:	342	331
BTFE:	3.9	3
APS injected:	2	3
Runtime monomer fed:		
TFE:	662	664
30 PMVE:	496	497
BTFE:	9.7	9.9

The polymerizations were run at 60° C for 651 minutes for Comparative Polymer A and 71° C for 262 minutes for Polymer A. Both polymerizations were run at a pressure of 16 bar.

In both cases a water clear transparent polymer latex was obtained. The latex was
 5 coagulated using 30 g $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$ in 1000 mL DI water. The polymers were filtered, washed several times with hot DI water and dried overnight in a circulating air oven at 100° C to form polymer gums.

The Mooney Viscosity (ML1+10 @ 121° C) of Comparative Polymer A was 76 and for Polymer A was 96.

10 One hundred parts by weight of each polymer gum was compounded by adding 15 parts by weight (phr) N990 carbon black, 5 phr zinc oxide, 1.5 phr Luperco™ 101 XL organic peroxide from Atochem and 2 phr triallylisocyanate-Dry Liquid Concentrate (TAIC-DLC; 72% active), available from Harwick, to each polymer gum.

Polymer A was compounded in a conventional manner on a two-roll rubber mill.
 15 The Comparative Polymer A had to be compounded on a heated (50-70° C) two-roll mill because it was crumbly and turned powdery if it was compounded in a conventional manner (i.e., using standard or unheated conditions).

Table 1 shows the rheological data obtained from the MDR testing.

Table 1

20	MDR (177°C)	Comparative	Compound A
		Compound A	Compound A
	ML (dNm):	5.1	3.0
	MH (dNm):	26	20
	t _{S2} (min.):	0.44	0.48
25	t'50 (min.):	0.65	0.68
	t'90 (min.):	1.51	1.76

As can be seen from the MDR data, Comparative Compound A showed a significant increase in ML (a measure of compound viscosity) compared to the Compound A, even though the Mooney viscosity of Comparative Polymer A was lower than that of
 30 Polymer A. In other words, even though the raw polymer viscosity of Comparative Polymer A was lower than that of Polymer A, the addition of the fillers, acid acceptors and

curatives made the compound viscosity of Comparative Compound A rise above that of Compound A.

The data shown in Table 2 was obtained after the compounds were cured. Comparative Compound A was press cured at 150°C for 10 minutes followed by post curing for 16 hours at 150°C and further post curing for 8 hours at 200°C. Compound A was press cured at 177°C for 10 minutes followed by post curing at 200°C for 20 hours. Attempts to cure and post cure the Comparative Compound A in the same manner as Compound A failed due to warping and formation of fissures in the test sample.

Table 2

	Comparative Compound A	Compound A
Tensile Strength (MPa):	24.5	19.6
Elongation at break (%):	165	136
100% modulus (MPa):	14.1	12.7
Hardness (shoreA):	87	80
Compression set O-rings, 70 hrs@ 200 °C:	42%	30%

The compression set resistance of Compound A was significantly better than that of Comparative Compound A. Comparative Compound A also required heated rolls for compounding, a lower press cure temperature and a two-stage postcuring.

EXAMPLE 2

These samples were made to demonstrate the reactivity of the polymer when compounding with a base or acid acceptor.

Polymer B was prepared in a manner similar to Polymer A except that no BTFE was used, 4 g of APS and 5.4 g C₄F₉SO₂Na were used, and the polymerization was run at 11.6 bar pressure.

Comparative Polymer B was prepared in a manner similar to that of Polymer B except that no sulfinate was used, only 1 g of APS was used, and the polymerization was run at 11.0 bar pressure.

The Mooney Viscosity (ML1+10 @ 121° C) of Polymer B was 38 and Comparative Polymer B was 73.

Comparative Polymer B was milled with 15 phr MT N990 carbon black and 6 phr Ca(OH)₂. The combination of ingredients started to exotherm and formed a crumbly

compound during milling. When the resulting Comparative Compound B was examined by MDR at 177° C, the torque of the crumbly compound increased from the initial 3.4 dNm to 17 dNm within 30 seconds and kept rising to 20 dNm in 10 minutes.

- Polymer B was compounded with the same additives as was Comparative
- 5 Compound B. The combination of ingredients remained as a viscous sheet on the mill and showed less than 1.1 dNm torque rise over 8 minutes on the MDR at 177° C.

- These results demonstrate the substantially lower reactivity of the compound of the invention when adding basic ingredients, such as acid acceptor. This difference is
- 10 apparent even in compounds where no cure site component is present.

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WHAT IS CLAIMED IS:

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1. A peroxide curable perfluoroelastomer compound that is easily processable comprising:

5 A) a perfluoroelastomer substantially free of ionizable end groups, said perfluoroelastomer containing interpolymerized units derived from 1) a perfluoroolefin, 2) a perfluorovinyl ether selected from the group consisting of perfluoro(alkyl vinyl) ethers, perfluoro(alkoxy vinyl) ethers, and mixtures thereof, and 3) a cure site component containing a halogen group capable of participation in a peroxide cure reaction, selected from the group consisting of fluorinated olefins having at least one such halogen group, fluorinated vinyl ethers having at least one such halogen group, chain transfer agents containing at least one such halogen group, and initiators containing at least one such halogen group, and mixtures thereof, with the proviso that the cure site component contains substantially no nitrile groups, and

15 B) a peroxide curative.

20 2. A peroxide curable perfluoroelastomer compound according to Claim 1, wherein the perfluorovinyl ether is selected from the group consisting of perfluoromethyl vinyl ether, perfluoroethyl vinyl ether, and perfluoropropyl vinyl ether.

25 3. A peroxide curable perfluoroelastomer compound according to Claim 1, wherein the halogen of the cure site component is bromine or iodine.

30 4. A peroxide curable perfluoroelastomer according to Claim 1, wherein the perfluoroelastomer is substantially free of ionizable end groups selected from the group consisting of carboxylate or carboxylic acid end-groups and sulfonate or sulfonic acid end groups.

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5. A method for improving the processability of perfluoroelastomers, comprising: polymerizing, under free-radical conditions, an aqueous emulsion or suspension of a polymerizable mixture comprising a perfluoroolefin and a perfluoroalkyl vinyl ether or a perfluoroalkoxy vinyl ether and mixtures thereof, a halogen-containing cure-site component that is capable of participation in a peroxide cure reaction, a fluoroaliphatic-radical containing sulfinate, and an oxidizing agent capable of oxidizing said sulfinate to a sulfonyl radical, with the proviso that the cure site component contains substantially no nitrile groups.

10 6. *The of claim 5, wherein the halogen-containing cure-site component is*
~~A method for improving the processability of perfluoroelastomers,~~
~~comprising: polymerizing, under free radical conditions, an aqueous emulsion or~~
~~suspension of a polymerizable mixture comprising a perfluoroolefin and a perfluoroalkyl~~
~~vinyl ether or a perfluoroalkoxy vinyl ether and mixtures thereof~~ a bromine-containing or
iodine-containing cure-site component, ~~a fluoroaliphatic radical containing sulfinate, and~~
15 ~~an oxidizing agent capable of oxidizing said sulfinate to a sulfonyl radical~~

7. A shaped article comprising the peroxide curable perfluoroelastomer compound of Claim 1.

20 8. A peroxide curable perfluoroelastomer compound according to Claim ¹ ~~7~~
wherein the perfluoroolefin is tetrafluoroethylene, the perfluoro vinyl ether is
perfluoromethyl vinyl ether.

9. A peroxide curable perfluoroelastomer compound according to Claim 1
25 wherein the cure-site component is said chain transfer agent.

10. A peroxide curable perfluoroelastomer compound according to Claim 1
wherein the cure site component is said chain transfer initiator.

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AMENDED SHEET